HIGH-FREQUENCY COMMUNICATION SYSTEMS

Lecture 6

Hasan T Abbas & Qammer H Abbasi

Spring 2023

- Beamforming
- Beamforming Algorithms
- Software Defined Radio

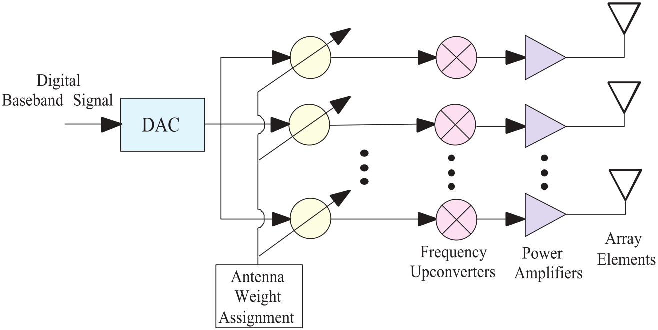


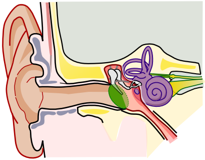
Figure 1: A typical beamforming architecture.

BEAMFORMING ALGORITHMS

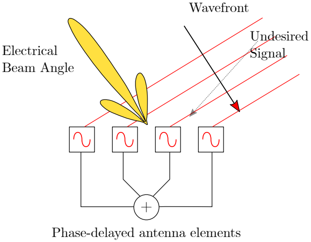
- For beamforming, determining the direction of an incoming signal through the direction of arrival (DoA) algorithms is a key element.
- The goal is to develop a machine like the human ear
- DoA or direction finding algorithms *reconstruct* the signals from each direction and try to determine the identity of the signal source.

$$S_i = \sum_{\ell=1}^{N} m_\ell(t) e^{-j\overrightarrow{k_\ell}\cdot(\overrightarrow{r_i}-\overrightarrow{r_1})}$$

here $\overrightarrow{k_\ell}$ is the wave-vector, $\overrightarrow{r_1}$ and $\overrightarrow{r_i}$ are the positions of the reference and i-th array elements.



(a)



(b)

We seek to construct a matrix, $\mathbf{X}$ for an array of M elements with N snapshots recorded in time.

$$\mathbf{X} = \begin{bmatrix} S_1(t_1) & \dots & S_1(t_N) \\ \dots & \dots & \dots \\ S_M(t_1) & \dots & S_M(t_N) \end{bmatrix}$$

Next, a covariance matrix $\mathbf{R}$ needs to be estimated for the incoming signal $\mathbf{X}$ polluted with noise N,

$$\mathbf{R} = \left(\frac{1}{N}\right)\mathbf{X}^*\mathbf{X}$$

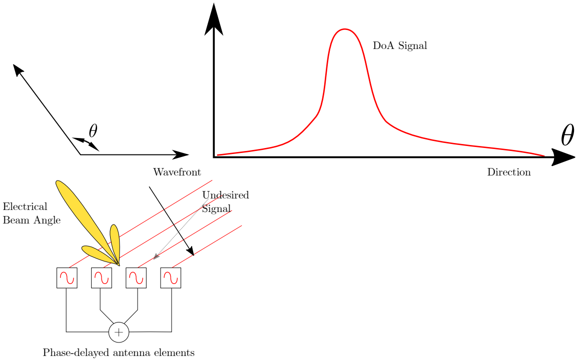
We also need to *track* the directions in which the array is activated. We represent this with a steering vector,

$$\mathbf{a}_{\text{direction}} = \begin{bmatrix} 1 & e^{-j\overrightarrow{k_l}\cdot\left(\overrightarrow{r_1}-\overrightarrow{r_2}\right)} & \dots & e^{-j\overrightarrow{k_l}\cdot\left(\overrightarrow{r_1}-r\vec{M}\right)} \end{bmatrix}$$

The next step involves the intensive computation of weights which will be applied to each direction vector:

$$\mathbf{w} = \frac{\mathbf{R}^{-1}\mathbf{a}_{\text{direction}}}{\left(\mathbf{a}^{*}_{\text{direction}}\,\mathbf{R}^{-1}\mathbf{a}_{\text{direction}}\right)}$$

- There are established ways to solve the above matrices
- Two of the most famous direction-finding algorithms are multiple signal classification (MUSIC) and estimation of signal parameters via rotational invariance techniques (ESPIRIT)
- Using some terminologies from Linear Algebra, both the algorithms above assume the covariance matrix column space is spanned by two orthogonal subspaces
  - They are signal and noise subspaces



θ
DoA Signal
θ
Wavefront
Direction
Electrical
Beam Angle
Undesired
Signal
+
Phase-delayed antenna elements

SOFTWARE DEFINED RADIO

- A communication system consists of many layers of operations.
- The physical layer is the most important of all.
- Typically, physical layer processing is done via dedicated hardware
- Radio is the technology through which signals are wirelessly transmitted and received
- Software-defined radio has some or all physical layer functions implemented via software

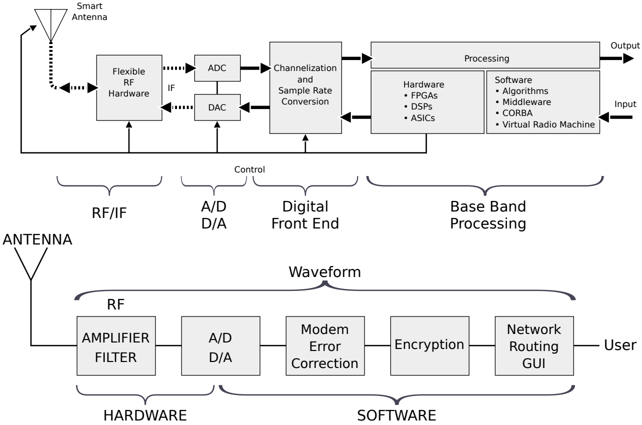


Figure 2: A Typical SDR workflow

- A graphical user interface consisting of *flowgraphs* through which different signal processing functions such as analogue-digital conversion can be performed.
- Some additions let us write `Python` codes within each block
- The software is meant to interface with Universal Software Radio Peripheral (USRP) modules to construct a complete communication system.

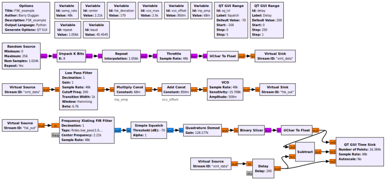


Figure 3: GNU Radio Interface.

Chapter 4

T. S. Rappaport, R. W. Heath, R. C. Daniels, and J. N. Murdock, Millimeter wave wireless communications. Upper Saddle River, NJ: Prentice Hall, 2015.